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23 Apr, 2009

From: Tullio Celano III P.E.
To: Underwriters of Rolling Boat, Inc.
Via: Phil Kazmierowicz, President, Rolling Boat, Inc.

Subj: **Explanation of Upper Level Capacity and Stability Characteristics for Rolling Boat, Inc. Vessels.**

Ref: a) ABYC Standards and Technical Information Reports for Small Craft
b) Code of Federal Regulations, Title 46, Shipping
c) U.S. Naval Academy, EN200 Course Notes

Executive Summary

This document is written to address questions concerning the configuration of the upper level of vessels designed and built by Rolling Boat, Inc., of Estacada, OR. From the beginning of the engineering development program for these vessels, stability and overall safety has been of primary importance. Rolling Boat, Inc., has retained a licensed, practicing Naval Architect throughout the development phase. Every decision involving weights and balances has been carefully evaluated with regard to transverse stability, ensuring that the numerical parameters are well within the limits set forth by applicable codes, and also make good engineering sense. The design process for the upper level has taken the same disciplined approach, and has been evolutionary in nature, with a combination of numerical simulations, physical tests of final articles, and real-world on-water testing.

Stability Basics

The standard methods for evaluating stability parameters of floating bodies have been employed to Rolling Boat's design. These methods involve, first, determination of the vessel's equilibrium immersion depth and attitude based on structural weight and loading, and then, computation of the vessel's response to changes in loading. In the theoretical sense, the parameters may be simplified to yield the classic, textbook relationships between imaginary points such as the Center of Gravity (CG), Center of Buoyancy (CB), and Metacenter (GM). In practice, computers are used to process this information on a piecewise basis to produce more accurate results than may be obtained through simplification as described here.

The CG of the vessel is simply the weighted sum of all masses that make it up. Additional weights added have the effect of increasing the displacement (Δ) of the craft, and moving the CG position toward the position of the added weight. Shifting of weights already aboard the craft have the effect of moving the CG point in the same direction of the weight shift.

The Center of Buoyancy (CB) of the craft is the geometric center of the displaced underwater volume. For objects such as a drilling rig, or a Rolling Boat, that have multiple displaced volumes, the CB is the weighted average of all of the underwater volume positions.

The Metacenter (M_T) is harder to understand. It is an imaginary focal point, located by determining the lateral shift in the CB as the craft heels through small (<7˚) angles. If the height of this metaceneter, usually referenced to the Keel point (K) is greater than the height of the CG, then the craft will have positive stability, and will have a natural tendency to restore itself to its lowest energy state, which is upright, on an even keel. If the position of the center of gravity were made too high, such that it rose above the Metacenter, then the vessel would be unstable, and would not stay upright. The difference in height between the CG and M is given the term Metacentric Height (GM_T). It is not correct to assume, however, that just because the vessel has a Transverse Metacentric Height of less than zero that it will immediately capsize. It may wallow off its upright condition to a position of stability at some list angle, and it may freely "loll" back and forth from one position of stability to another. Or, if the vessel does not have this secondary point of stability, it will indeed capsize. In any event, when the GM_T value drops to the level where this behavior is exhibited, it will with near certainty fail to pass legislated stability criteria, and will be unsafe for operation in a seaway. Figure 1, shows the relative positions of the points discussed above, and what occurs as the vessel heels to an exaggerated angle due to a shift of the weight "w".

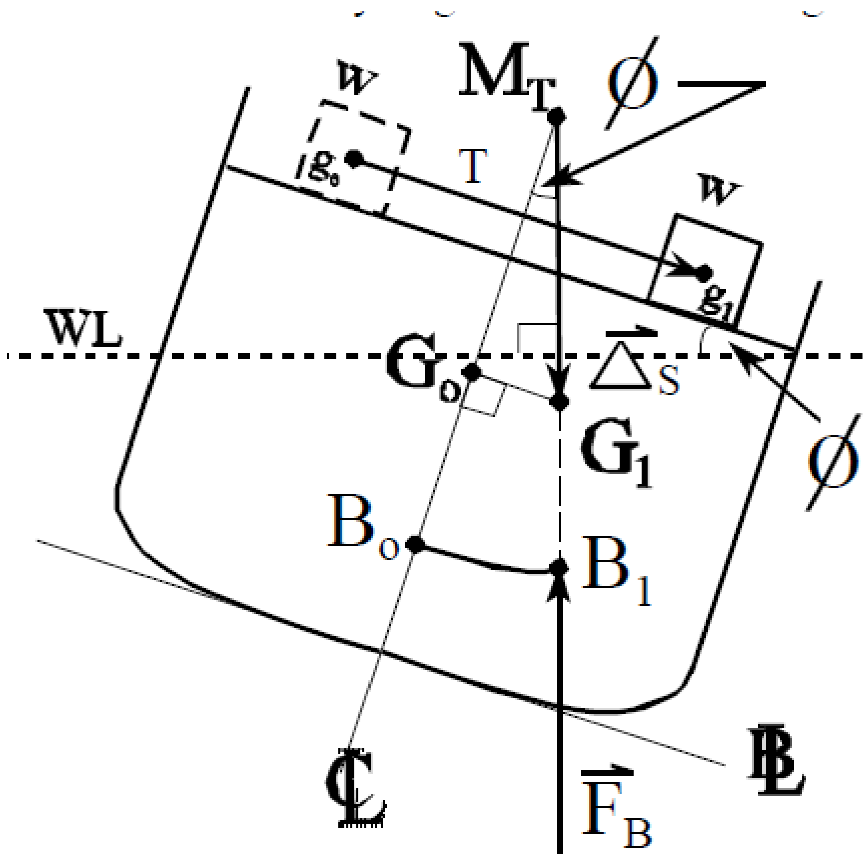

Figure 1 – Body Plan Diagram Showing Points B, G, and M_T

As seen in Figure 1, a lateral shift in weight causes the CG point to shift parallel to the weight shift. The distance by which G shifts will be proportional to the weight of the shifted weight versus the total weight of the craft, according to the following equation, where "TCG" refers to the transverse position of the Center of Gravity.

$$TCG_{new} = \frac{\pm TCG_{old}\,\Delta_{s\ old} + \sum_{i=1}^{N} (\pm w_i)(Tcg_i)}{\Delta_{s\ new}}$$

Similarly, upward shifts or additions in weight above the center of gravity cause the vessel's CG point to move upward. A similar equation, where KG measures the distance between the Keel, or reference point and the Center of Gravity is:

$$K\overline{G}_{new} = \frac{K\overline{G}_{old}\,\Delta_{s\ old} + \sum_{i=1}^{N} (\pm w_i)(K\overline{g}_i)}{\Delta_{s\ new}}$$

So, it is seen that the TCG value affects the list angle at which the vessel will float in equilibrium, and the KG value directly controls the value of GM_T, which governs the response to an off-center TCG via the following equations:

$$GM_T = KM_T - KG$$

$$\Delta_s\,\overline{G_0 M_t}\,\tan\varphi = w\,t$$

The last equation can be re-written as:

$$\tan\phi = \frac{TCG}{GM_T}$$

showing that the list angle is directly proportional to the lateral position of the TCG, and a function of the GM_T value.

Application to Rolling Boat Barge

The final weight and CG position of the Rolling Boat may be determined analytically through careful inventory of all of the components that are used to constructed, or experimentally, once launched using standard Naval Architectural methods. Similarly, the GM_T value can be

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determined through analysis, or by direct experiment. Computer-numerical methods actually bypass this simplification, to simulate actual equilibrium conditions, outside of the linear ranges of the above equations. This is the process by which Rolling Boats have been evaluated, using the top-level industry hydrostatics software package, called GHS (General Hydrostatics), by Creative Systems, Inc. This is the software package used by most large Naval Architecture firms to manage the hydrostatic computations for ship and offshore structure programs.

When considering installation of the upper level for Rolling Boat, Inc., due diligence has been paid to ensuring that the geometry of the upper level was such that loads due to a maximum number of passengers would be constrained to an area that would not cause the combination of rise in KG and transverse shift in TCG to result in either reduction in GM_T, the stability parameter, to a dangerous level, or an excessive angle of list. In fact, the resulting list angle is less due to having all allowed passengers crowd the upper level rail than if they were to crowd the lower level railing. In performing these simulations, the center of mass of the people on the upper level has been taken even closer to the railing that would be realistic, even with people packed on top of each other. A typical condition computed for a Rolling Boat “Big Barge” series, with a full load of people, all on the upper level, results in a GM_T value of over 16’. A value over 0.49’ is legal, and anything over 4’ is considered exceptionally stable. The nature of the Rolling Boat’s extremely low, wide structure and wide placement of outrigger wings provides vastly more initial stability than seen on almost any other waterborne craft produced today, with the exception of large deck barges.

Figure 2 shows, using a computer-generated image, the equilibrium condition with passengers distributed equally about the deck.

Figure 2 – Initial Condition with Passengers Equally Distributed

Figure 3 shows the list angle developed when all of the approved passengers crowd to one side of the vessel. This is roughly equivalent to the condition actually tested using weights during the ABYC capacity test procedure.

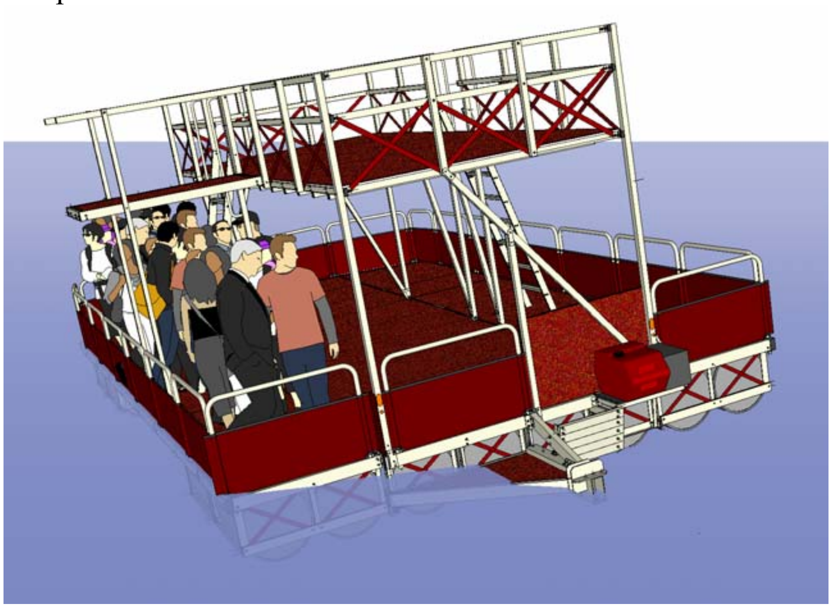

Figure 3 – All Passengers on Lower Level to Port Side

Figure 4 shows the equilibrium condition when all passengers crowd the railing on the upper level. Note that the resulting list angle is nowhere near as severe.

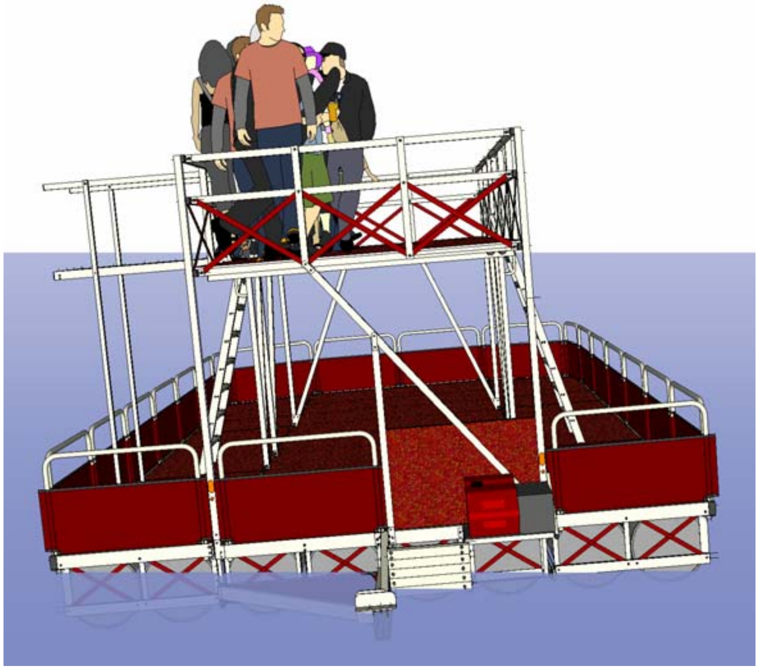

Figure 4 – All Passengers on Upper Level to Port Side

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Righting Arm Concepts

While initial stability, or stability in the linear range of heel angles within approximately ± 7˚ of centerline is governed by the simple relationships described above, and is the subject of several USCG requirements, the vessel's response at higher angles, of heel, all the way to capsizing, can be analyzed and quantified by measuring the vessel's Righting Arm (GZ). The righting arm is defined as the amount of righting moment being generated by the force couple passing through the points B and G, as shown in Figure 5, divided by the weight (Δ) of the craft.

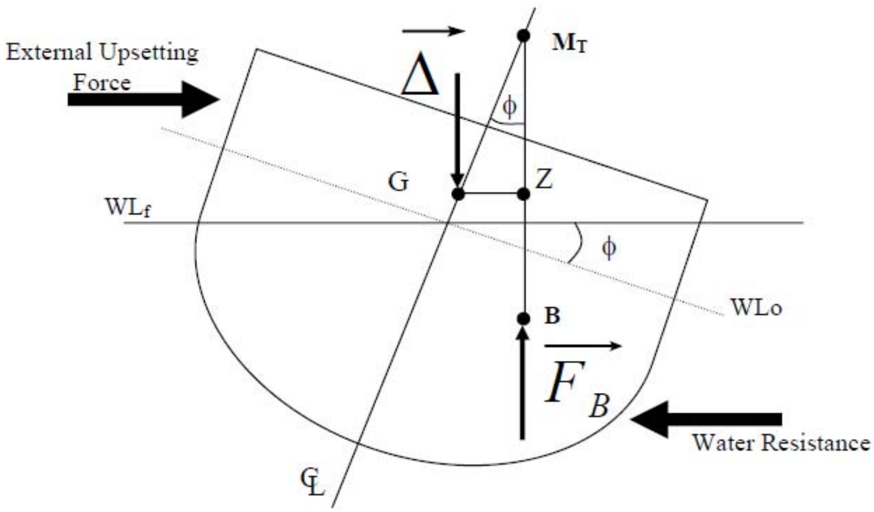

Figure 5 – Body Plan Diagram Showing Righting Arm (GZ)

Although no actual case of static equilibrium exists for a vessel operating in a real environment, it is satisfactory to assume that the vessel may be in a quasi-static condition momentarily, in which the overturning, or heeling moment (HM) and the righting moment (GZ) are equal and opposite. In this condition, as shown in Figure 5, the vessel would remain stationary. Rules and regulations promulgated by the USCG, and other organizations mandate requirements on the shape and characteristics of a vessel's righting arm curve, which as before, becomes a direct function of the weight, loading condition, and underwater geometry of the vessel.

There are no specific legal requirements for vessels of this size and typically the USCG does not require any formal righting arm computations for this type of vessel. Never-the-less, righting arm computations were completed for Rolling Boat craft, for informational purposes, and for peace of mind of the Naval Architect. The vessel exhibits righting arm characteristics typical of wide, low deck barges, and thus was compared to the legal requirements for loaded deck barges. 46CFR174.015 requires that an ocean-going barge have 15 ft-deg of righting energy, which corresponds to the area beneath the righting arm curve, up to the angle of maximum righting arm. Even with all passengers loaded on the upper level, this criteria could be met., with 18.45 ft-deg. 46CFR170.173e(1) applies to passenger vessels of more conventional form, and has the same righting energy requirement, and adds requirements on downflooding points and range of

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stability. The Rolling Boat can maintain positive righting arm with the upper level loaded, up to heel angles of 38˚, exceeding the requirement of 35˚. Once the GZ value drops to 0, the vessel will cease resisting further heeling, and will capsize on its own accord.

Conclusion

As shown in the example above, the configuration of the products offered by Rolling Boat, Inc., have been designed and engineered to be inherently safe. As long as users do not violate the maximum number of passengers posted on the vessel's USCG placard, the risk of capsizing is very low. Each different vessel offered by the company will receive the same type of rigorous stability evaluation to ensure that it will meet regulations and provide reliable service under the intended conditions.

Sincerely,

Tullio Celano III P.E.
President, Crescere Marine Engineering, Inc.